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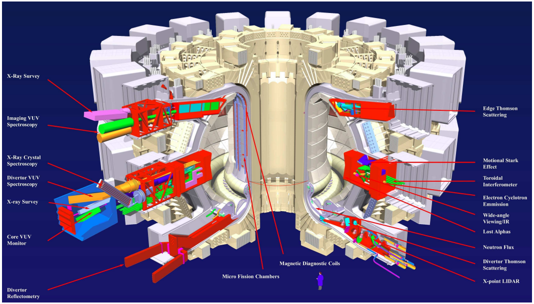
Application of rarefied gas dynamics for design of the ITER optical diagnostics

64th IUVSTA Workshop, May 16-19th 2011 | V. Kotov, D. Reiter, IEK-4 - Plasma Physics

Mirrors in ITER

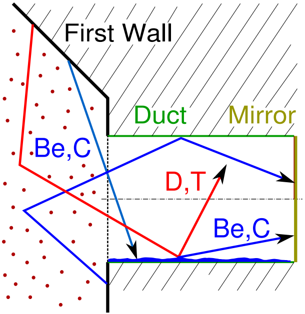
- Optical diagnostics bring most of information about plasma



the picture is a courtesy of ITER www.iter.org

- Mirrors redirect light to the protected instruments
- First mirror faces the plasma directly
- Degradation of reflectivity due to incident particles

Degradation of the mirrors



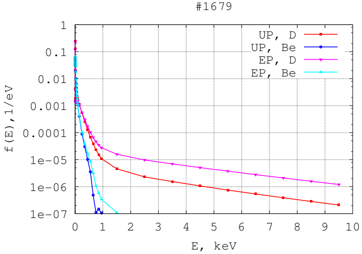
- Protected in the diagnostic ducts: no direct ion fluxes
- Fast atoms (D, T, He): erosion
- Impurities (Be, C, Fe, W etc): formation of deposits
- Flux to the mirror $<$ aperture flux
- **How effective is the protection?**

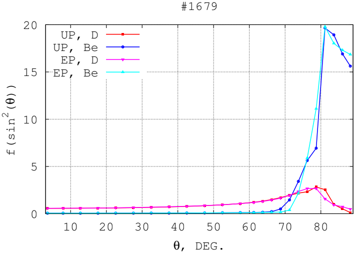
- Free molecular flow approximation (MFP$>$3 m, size$\sim$1 m) $\Rightarrow$ straightforward numerical modelling

Special feature 1: non-thermal incoming particles

3D distribution function $f\ (E, \theta, \phi)$. Neutral particles come:

- From the plasma facing components
- From plasma: charge-exchange and elastic collisions

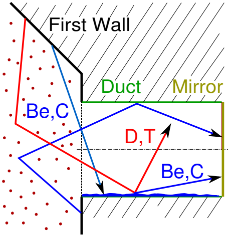




- “Reflection“ from $\sim$keV plasma: high-energetic tail of D, T
- Distribution of sources: grazing incidence prevails

Special feature 2: particle-surface interaction

- Reflection coefficients $R(E, \theta; E', \theta')$ for fast, $>$10 eV, particles (D, T, He):
  - Binary collisions with lattice atoms
  - TRIM code, W. Eckstein, IPP Garching
- Reflection coefficients of impurities (Be, C etc.):
  - Empiric, molecular-dynamics



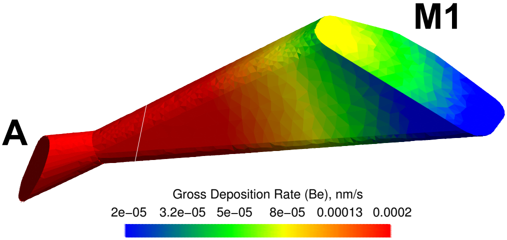
- Important process: sputtering of deposited films from the duct wall
- Caveat: the data on impurity reflection and the sputtering of deposits are incomplete and uncertain
- **Parametric studies and worst cases**

The numerical tool: EIRENE

$$\frac{\partial f(\mathbf{r},\mathbf{v},t)}{\partial t} + \mathbf{v}\cdot\nabla_{\mathbf{r}} f(\mathbf{r},\mathbf{v},t) = Q(\mathbf{r},\mathbf{v},i,t) +$$
$$+\int\int\int \sigma(\mathbf{v}',\mathbf{V}';\mathbf{v},\mathbf{V})|\mathbf{v}'-\mathbf{V}'|f(\mathbf{v}')f_b(\mathbf{V}')d\mathbf{v}'d\mathbf{V}'d\mathbf{V}-$$
$$-f_b(\mathbf{V})\int\int\int \sigma(\mathbf{v},\mathbf{V};\mathbf{v}',\mathbf{V}')|\mathbf{v}-\mathbf{V}|f(\mathbf{v})d\mathbf{v}'d\mathbf{V}'d\mathbf{V}$$

- Linear Monte-Carlo particle transport code
  - Fixed background for test particles
- Primary application: interaction of magnetized plasma with rarefied neutral gas
  - Models for elementary processes, particle-surface interaction
- Arbitrary 3D geometry, MPI-parallelized
- Widely used in magnetic fusion community
- Developed at FZJ by D. Reiter et al., see www.eirene.de

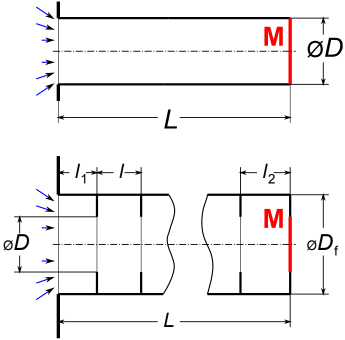
The results of parametric studies



- An example: core-CXRS diagnostic
- ANSYS-generated grid for CAD geometry

- Experimentally found limits for *erosion* can be reached after $>$10000 ITER discharges. Good :-)
- ... for *deposition*: after 1-1000 discharges. Too bad :-(
- Impurity flux attenuation by a factor $\sim$100: <u>factor $>$10000 is desirable</u>

Protection by baffles



Example:

- Impurity reflection coefficient R_N= 0.1
- Enhanced re-erosion

Attenuation factors (L/D=20):

W/o baffles: $<$1500

With baffles: $<$20000 (!)

$(D_f = 2D,\ l_1 = 0,\ l_2 = 2D,\ l = D)$

But this is not a universal solution:

- Relies on R_N $<$1, formation of molecules: $R_N \rightarrow 1$
- Geometry is not suitable for all diagnostics

Protection by gas puff as an option ???

- Possibly small flux: to minimize disturbance of plasma!

Summary

- Life-time and performance of the ITER optical diagnostics is limited by the degradation of mirrors
- Protecting effect of the diagnostic ducts has to be estimated
- Free-molecular flow problem with two special features:
  - Non-thermal sources of test particles
  - Complex particle-surface interaction
- The 3D test particle Monte-Carlo code EIRENE is applied
- Analysis shows that erosion can be effectively reduced
- But reduction of deposition could be insufficient
- Protection by gas puff (transition flow!) may be an option

This work has been done in frame of the ITER Service Contract C4T/09/71/OLT CHD/DIAGNOSTIC